AD-A086 656 LOUISIANA STATE UNIV BATON ROUGE DEPT OF ELECTRICAL --ETC F/G 5/8
A STUDY OF TEXTURE ANALYSIS ALGORITHMS.(U)
APR 80 C A HARLOW, R W CONNERS F49620-79-C-0042
UNCLASSIFIED AFOSR-TR-80-0505 NL

1 OF 1
AD A086656

END
DATE
FILMED
8-80
DTIC

AFOSR-TR- 80-0505

RESEARCH STUDIES IN ELECTRICAL ENGINEERING

3

Annual Technical Report
on
AFOSR Grant

A STUDY OF TEXTURE ANALYSIS ALGORITHMS

by

C. A. Harlow
R. W. Conners

April 7, 1980

Contract Number
F49620-79-C-0042

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO. AD-A086656	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) A STUDY OF TEXTURE ANALYSIS ALGORITHMS		5. TYPE OF REPORT & PERIOD COVERED Interim
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) Charles A. Harlow, Richard W. Conners		8. CONTRACT OR GRANT NUMBER(s) (15) F49620-79-C-0042
9. PERFORMING ORGANIZATION NAME AND ADDRESS Louisiana State University, Electrical Engineering Department, Baton Rouge, Louisiana 70803		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 61102F
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Office of Scientific Research/NM, Bolling AFB, Washington, DC 20332		12. REPORT DATE April 23, 1980
		13. NUMBER OF PAGES 13
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) (11) 23 Apr 80		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited. (12) 27

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

(18) AFOSR (19) TR-80-0505

18. SUPPLEMENTARY NOTES

(9) Annual rept.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Image Processing, Texture Analysis, Structured Analysis and Evaluation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This research has focused upon evaluating and developing texture analysis algorithms. During the current year theory has been developed for evaluating texture analysis algorithms. It has been shown that the Spatial Gray Level Dependence algorithm is a superior algorithm under fairly weak assumptions. The assumption required is that the textures be translation stationary random fields of order two. Under these assumptions, the SGLDM algorithm is superior to the Power Spectral Method, the Gray Level Run Length Method and the Gray Level Difference Method. The SGLDM algorithm has therefore been the focus

DD FORM 1 JAN 73 1473

405152

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

#20 of our subsequent work. Efforts have progressed on developing a combined structural and statistical texture analysis algorithm. Methods have been developed for characterizing the unit cell which gives the basic repeated texture pattern. Combined with a study of the unit cell has been the development of a mosaic model for textures that utilizes tiling theory. Tiling theory provides the basic mathematical structure required for analysis.

ABSTRACT

This research has focused upon evaluating and developing texture analysis algorithms. During the current year theory has been developed for evaluating texture analysis algorithms. It has been shown that the Spatial Gray Level Dependence algorithm is a superior algorithm under fairly weak assumptions. The assumption required is that the textures be translation stationary random fields of order two. Under these assumptions, the SGLDM algorithm is superior to the Power Spectral Method, the Gray Level Run Length Method and the Gray Level Difference Method. The SGLDM algorithm has therefore been the focus of our subsequent work. Efforts have progressed on developing a combined structural and statistical texture analysis algorithm. Methods have been developed for characterizing the unit cell which gives the basic repeated texture pattern. Combined with a study of the unit cell has been the development of a mosaic model for textures that utilizes tiling theory. Tiling theory provides the basic mathematical structure required for analysis.

TABLE OF CONTENTS

1. Introduction

Texture analysis is an important facet of image analysis systems. This research project is concerned with developing a better understanding of texture analysis algorithms. Specifically we are concerned with (a) evaluating existing texture analysis algorithms (b) determining measures which accurately represent the features used by humans in discriminating texture patterns (c) developing methods for creating superior texture analysis algorithms.

It is felt that the progress during the current year has been substantial. Since this was the first year of the contract, progress had to be made in two areas. One goal that had to be achieved was to create a support environment for research in image analysis. This goal is important if progress is to be made in image analysis research. The support environment includes hardware, software installation and development, staff additions and training, student training and course development. Substantial progress has been made in these areas. A powerful image processing system has been purchased and installed. This system will allow the support software for this project to be speedily developed in a modular form. Other support activities include developing courses and training graduate students in image processing. During the first year, two image processing courses have been developed and taught. Presently six electrical engineering students are working on image processing projects. The first year has been important in developing these support functions and we feel that there has been substantial progress in this area.

The second area of progress was to achieve the goals of the grant in developing texture analysis algorithms. This progress can be measured by observing the resultant conference and journal publications. A substantial number of papers have been presented. But beyond this there remains the more fundamental concern about understanding texture analysis. We feel substantial progress has been made in this area. Progress has been made in evaluating texture analysis algorithms and in developing useful measures. The work on evaluating texture analysis algorithms has shown that the Spatial Gray Level Dependence Method texture analysis algorithm is a superior algorithm under fairly weak assumptions. The assumption required is that the textures be translation stationary random fields of order two. These results show that SGLDM texture analysis procedure is theoretically a superior method than the Power Spectral Method, The Gray Level Run Length Method or the Gray Level Difference Method. This allows one then to base further investigations upon the SGLDM texture analysis algorithm. The SGLDM algorithm for this reason has been used in subsequent work deriving measures which relate to human perception of texture patterns. A focus of this work has been to develop a combined structural and statistical algorithm for texture analysis. This work has focused upon developing methods for characterizing the unit cell which represents the basic texture pattern. Methods have been developed for determining the unit cell based upon measures of the general form of the Inertia Measure considered as a function of intersampling spacing distance. These measures have been shown to be of general utility in texture discrimination. Combined with a study of the unit cell has been the development of a mosaic model for textures that utilizes tiling theory. Tiling theory provides the mathematically structure required to place the analysis on a theoretically sound basis for analysis.

2. Objectives

The objectives of the grant during the first year was to

a. Evaluate and Compare the capabilities of texture analysis algorithms.

b. Evaluate texture analysis algorithms for their ability to discriminate texture patterns perceived by humans.

c. Develop a set of features which will match image parameters believed to be used by humans in discriminating textures. These include the detection of periodic patterns in textures, the size of the periodic patterns (i.e., the unit cell size), and a measurement of the Gestalt principles of proximity and uniformity.

Since we need the capability to process synthetic and naturally occurring texture patterns a support objective was to develop a flexible, modular image processing system capable of handling remotely sensed data.

3. Status of Research

3.1 Texture Algorithm Evaluation

Methodologies for evaluating texture analysis algorithms are very important. Without such methodologies and the results gleamed from their use, it is difficult for either the image analysis practitioner or theoretician to make progress.

Previous attempts to evaluate texture algorithms have used the percentage of overall correct classification as the metric of performance. We refer to this method as the classification result comparison (CRC). Unfortunately the CRC evlauation procedure has severe disadvantages. One disadvantage is that the comparison is valid for only the particular data base under consideration. The second is that the results do not provide any insight into the texture discrimination power of the texture analysis algorithms under consideration. Since our ultimate goal is to develop improved algorithms, it was important to develop a comparison method that would provide the type of information not available from the CRC.

The result of our investigations was a theoretical comparison procedure. This evaluation methodology was the first to present a comparison based upon the intermediate matrices of the texture analysis algorithms. The advantage of this approach is that the evaluation does not depend upon a data base or measurements derived from the intermediate matrices. The evaluation is based more upon the intrinsic discriminatory power of the algorithm. The evaluation method utilizes the Markov generation procedure first mentioned by Julesz as a method to study the basic texture discriminatory power of humans. This methodology is useful in generating texture patterns to support or disprove hypotheses. In particular it is useful in demonstrating such facts as a particular measure does not discriminate a particular texture pattern. For such a hypothesis it is sufficient to generate one example of a texture pattern discriminable by humans that have the same value for the given measure. The comparison study involved a comparison of the texture discrimination power of the four algorithms:

a. SGLDM - Spatial Gray Level Dependence Method

b. GLRLM - Gray Level Run Length Method

c. GLDM - Gray Level Difference Method

d. PSM - Power Spectral Method

These algorithms were chosen because they are frequently used algorithms and therefore provide a meaningful test of the procedures developed.

The initial results using the theoretical comparison procedure were limited to textures which could be represented as a special class of Markov generated random fields. The results from these very simple textures indicated that the SGLDM was the most powerful of the four algorithms.

During this granting period the results obtained from using the theoretical comparison procedure have been extended to a much broader class of textures. Indeed, the only procedure that must be met by the textures is that they be translation stationary of order two. Over this very broad class of textures, the result of the theoretical comparison procedure still indicate that the SGLDM is the most powerful algorithm of the four.

The generalized results obtained during the granting period are reported in Publication 4.

The results of this evaluation of texture analysis algorithms have led the investigators to concentrate on developing a new improved algorithm based on the spatial gray level dependence matrices.

3.2 Unit Cell Size Determination

Much work during this granting period has been spent on developing a combined statistical/structural analysis system. This work has centered upon determination of the size, shape and orientation of the basic unit cell for repetitative texture patterns, a method for determining the placement rules for the unit cell and methods for measuring properties of the texture patterns. The basic theoretical model used for developing this statistical structural analyzer consists of the following.

a. Primitives - consisting of a set of prototiles and functions for coloring the tiles.

b. Ideal Texture - consisting of the primitives together with placement rules for tiling in the plane.

c. Ideal texture picture function $g(\overline{X})$ - consists of the ideal texture.

d. Transformation T - this transformation maps the ideal texture pattern into the observed texture pattern.

e. Surface picture functions $g_s(\overline{X})$ - this is the observed picture which is a distorted or transformed version of the ideal pattern.

Tiling theory admits a conveneint way to characterize primitives. In this formulation a primitive is a set $\{T,f\}$ where T is a subset of the plane (E^2), and $f:T \rightarrow R$. A set $Sp = \{\{T_1,f_1\}, \{T_2,f_2\},\ldots, \{T_n,f_n\}\ldots\}$ is an admissible set of primitives if there is at least one tiling of the plane possible using the tiles in Sp. An element $\{T_i,f_i\}$ of S_p is then called a unit pattern.

Ideal textures can also be described. A placement rule is an isometry that maps T onto E^2. Given a set S of tiles a set R_p is called an admissible set of placement rules of S if the isometries in R can be used to tile in the plane using the tiles of S. An ideal texture is a pair $I_T = \{S_p, R_p\}$. An ideal texture defines a picture function g $(\bar{X})$.

A consequence of this formulation is the fact that given a picture $g_s(\bar{X})$ there is not a unique ideal texture respresentation for $g_s(\bar{X})$. One can however restrict the choices by selecting the tiling which has the smallest number of unit patterns and the simpliest placement rules. Results obtained indicate that for periodic textures one can choose an ideal texture representation S_p which contains only one unit pattern whose placement rules R_p are defined by the shape of the unit pattern. The unit pattern shape and placement rules are defined by two vectors. Stated more precisely:

Given a periodic texture $g(\bar{X})$ there exists a parallelogram tiling T_p and a function defined f defined on the prototile p of T_p such that for any T_i in T_p and $\bar{X}$ in T_i then $g(\bar{X}) = g(\sigma^{-1}(\bar{X}))$ where σ is the isometry which maps p into T_i.

It is important to relate these results to the analysis of texture patterns. One can apply the criterion that the same texture should always give the same size and shape unit cell. This leads to the restriction that one considers angles in the range $0 \leq \theta < 180°$ and picks the two vectors $\bar{a}$ and $\bar{b}$ so that they have minimum magnitudes. Figure 1 shows how the vectors $\bar{a}$ and $\bar{b}$ define both the size, shape and orientation of the period parallelogram unit pattern as well as the placement rules of this pattern.

To see how the inertia measure can be used to detect periodicity in a texture consider the simple texture pattern shown in Figure 2. Further, let us restrict our attention to the ...

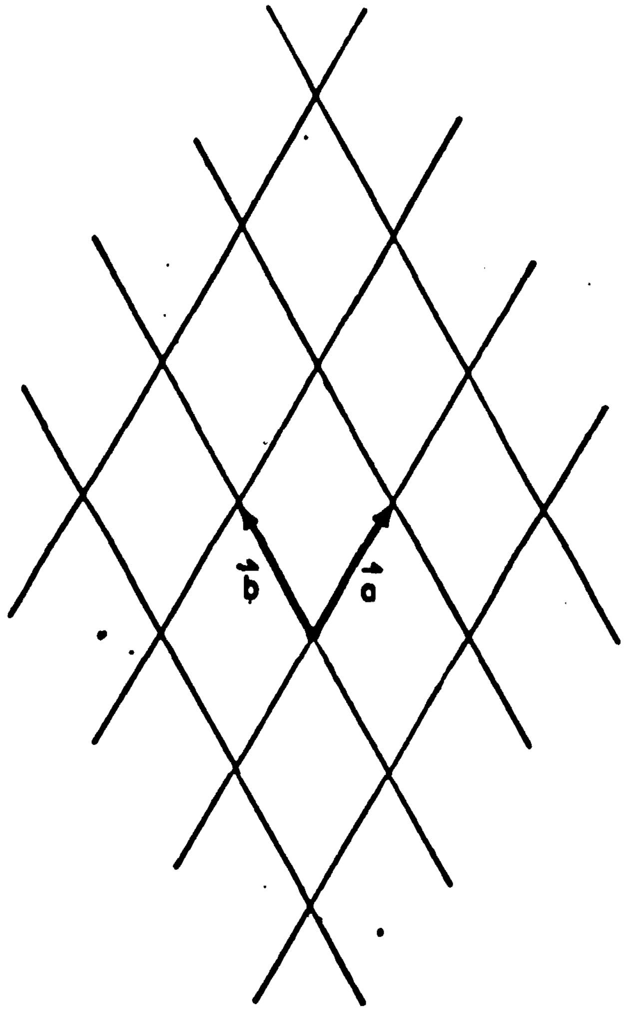

Figure 1. Two vectors $\bar{a}$ and $\bar{b}$ completely define the prototile and the placement rules of a period parallelogram unit pattern

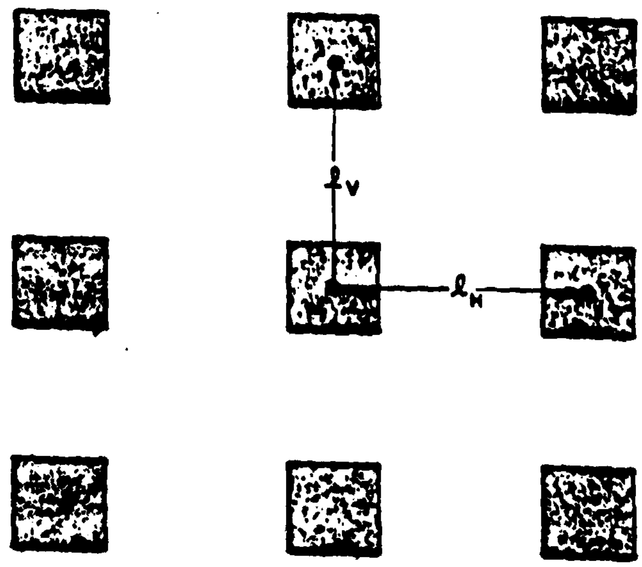

Figure 2. A simply periodic texture composed of squares which are regularly spaced on a white background

direction with period ℓ_H. The following is true for the horizontal spatial gray level dependence matrices $S_0(d)$, $d = 1,2,\ldots$.

1. $S_0(\ell_H)$ is a diagonal matrix.

2. $S_0(d)$, $d = 1,2,\ldots,\ell_H-1$ are not a diagonal matrices.

3. $S_0(\ell_H+n) = S_0(m\ell_H+n)$, i.e., the matrices are periodic with period ℓ_H.

These three properties indicate that the inertia measure can be used to detect the periodicity of the texture when $\theta = 0°$.

It should be clear that the above properties generalize very well. For any angle θ the inertia measure can be used to detect this periodicity.

The following observations are true about the inertia measure.

a. The inertia measure provides a least square estimate of the period.

b. For translation stationary random fields the Inertia measure is equivalent to the power spectrum.

c. The Inertia measure is equivalent to the correlation function.

By considering the various angles and d's the Inertia measure can be used to:

a. determine the size, shape and orientation of the unit parallelogram pattern.

b. determine the placement rules of the unit parallelogram.

Some results have also been obtained on textural coarseness and the selection of measures to be used with the SGLDM texture algorithm. Related to textural coarseness one can note that the Inertia measure has the property

$$I_\theta^\mu(d) = I_\theta(d/\mu)$$

where μ is the magnification of the image. It would appear that this gives insights into the analysis of nonperiodic textures but this remains to be explored.

The results of these investigations are described in detail in Publication 7.

3.3 Proximity and Uniformity Measures

As part of the development of the statistical structure analyzer other features are being investigated. In particular features are being sought which measure the perceptual concepts of uniformity and proximity.

Actually this effort may be broken down into two parts. The first part concerns developing design guides for generating new features for the SGLDM in general. The second part of this work concerns features which measure the uniformity and proximity perceptual concepts in particular.

When one is defining new features to be used by any image processing system care must be exercised. Consequently care must be used in defining other features to use with the SGLDM besides the inertia measure. If one were to just arbitrarily define additional features the result could be a large feature set whose total discriminatory power could be little more than that of just the inertia measure.

Ideally, one wants a small feature set, the smaller the better. Also, ideally one wants each feature in the feature set to contribute it's own unique type of information about the pattern. That is, one desires some sort of feature independence.

This leads us to a set of design guidelines for arriving at a new feature set for the SGLDM. It should be noted that while these guidelines do not guarantee uniqueness in the feature formulation process they do embody many of the desirable traits one would like in a feature set.

These ideal design guidelines are as follows:

1. Each feature should measure a visually perceivable quality of a texture.
2. The features should all be independent.
3. Given any visually distinct pair of textures there should be at least one feature in the feature set whose computed value

is different for the two textures comprising this texture pair.

The meaning of "independence" mentioned in design guideline number two can best be explained by an example. Suppose that one has three features, F1, F2, F3. These three features are said to be independent if

i) There exists a visually distinct texture pair such that the values of features F2 and F3 are the same for both textures in the texture pair but the value of F1 is different for the two textures.

ii) There exists another visually distinct texture pair such that the values of features F1 and F3 are the same for both these textures but the value of F2 is different.

iii) There exists a third visually distinct texture pair such that the values of features F1 and F2 are the same for both these textures but the value of feature F3 is different for these two textures.

The extension of this concept to n features is straightforward.

These guidelines guarantee minimum number of "uncorrelated" features, each of which measures some visually meaningful quantity.

It is under these guidelines that features measuring uniformity and proximity will be developed as well as any other features which may be developed for use with the SGLDM.

It has been shown that there is a texture pair that cannot be discriminated by the Inertia measure. Therefore the design guidelines stated above demand at least one more measure be added to the feature set. Analysis of examples indicate that measures of the form

$$\sum_{\ell} (\ell-\mu)^{2n-1} h(\ell,d,\theta) \tag{1}$$

are pertinent where

$$h(\ell,d,\theta) = \sum_{i} \sum_{j} s_\theta (i,j|d)$$

$$|i-j| = \ell$$

and

$$\mu_\ell = \sum_\ell \ell h (\ell,d,\theta).$$

Also, it is believed that measures of the form

$$\sum_\ell (\ell-\mu_\ell)^n h(\ell,d,\theta)$$

are useful.

It is believed further that at least one feature of the form given by Equation 1 and at least one feature of the form given by Equation 2 are needed to measure the perceptual concepts of uniformity and proximity.

The results presented here are preliminary but indicate the direction of future work.

For a more complete description of this work see Publication 7.

3.4 Computer System Development

In this section we would like to discuss the comprehensive computer hardware and software system that has been configured, purchased and implemented during the last year to support image processing activities at LSU in general and this contract in particular. It should be noted that while this is a basic research grant to test the robustness of the mathematical formulations developed, one is required to write computer software. Having a large dedicated computer system impacts the investigator's performance in two very important ways. First it reduces software development time. Secondly it allows interactive systems to be developed. Using interactive methods to process data allows one to quickly determine algorithm performance levels and also allows one to develop mathematical intuition into any possible problems which might be present. This intuition can be used to fuel further theoretical studies.

The system that has been developed consists of a modern 32-bit processor (Interdata 8/32), with a Comtal interactive Color display, an electrostatic plotter and other related peripherals.Also an NSF research equipment grant has recently been awarded to acquire a camera/scanning system. Another computer for research and educational uses has been installed in the Electrical Engineering Department. This is an Interdata 3220 system and related equipment. During this contract period $400,000 in computer and image equipment will have been installed. In addition software installation and development worth more than $50,000 has been developed and installed. This includes the Interdata system software as well as drivers and plotting packages for the peripherals on the system. A software system to support image processing research and development has also been installed.

The system implemented has been designed for ease of user operation, ease of integrating new modules and transportability to other systems. The image analysis system can be decomposed into two components, the kernel system and the application modules. The entire system is written in FORTRAN. Some machine dependent programs are used to accomplish input/output. A part of the system is resident at all times but most of the modules are resident only when a particular application requires them.

The kernal system maintains system subfiles and data files. It enables the user to easily access and maintain files. The subsystems central file stores all support information required. The subsystem control file is an index file which stores all non-imagery and applications support information required. The actual information in this file is determined primarily by the application modules being used.

The structure of the control file is fixed relative to the application modules but flexible relative to user needs and machine dependent file structures. The control file is composed of subfiles, the first of which is control file directory. This 240 (32-bit) word subfile is also held in memory during operation. The size and format of all other subfiles are based on the demands the user places on the application modules. The present subsystem can maintain up to 117 subfiles, each with the option of containing a 240 byte comment record. The subfiles can be used to store pseudo color tables, function memory arrays, statistics, polygon coordinates, and any information generally passed through common blocks for calling lists. When possible these subfiles are handled in a manner transparent to the user. In other situations the user is prompted to supply information necessary to determine the characteristics of the subfile.

The system is designed for easy access to any overlay. Application modules that are directive oriented will check all invalid directives against an overlay list. If the command entry matches an entry in the list, the subsystem immediately exits from the present module and loads the requested overlay. The user also has the capability to demand the load of any overlay within the system but not part of the subsystem overlay list.

The application modules rely on the kernal system for machine dependent functions. The applications I/O support and interface subroutine provided the application modules with the capability to accomplish high volume I/O, manipulation of display devices and data base file allocations. The user can specify a window of data, element and scan line increments and channels with a picture file viewed. The Comtal Display programs allow the user to view and dynamically enhance an image through the use of the function memory, pseudo color tables and graphic overlays. It can expand an image and very the contrast of an image. Operation of the trackball allows one to manipulate the image by passing it through a sine, arch tangent or linear function. Pseudo color enhancements allow the user to highlight classes, alter pseudo color tables, invert and switch colors. The user can display 64 colors or display 256 gray levels. The subsystems can return the scan line and element numbers and pixels to values of any position in the image. The display can be specified to show only one scene or to display up to 4 scenes or channels of data at once. Polygons can be outlined by the user for statistical analysis or automatically classify pixels.

The basic texture analysis programs are presently operating upon the Image Processing System. This required converting all the programs from a PDP 11 system to the current system. This software includes the measurement extraction programs for the SGLDM texture analysis method. The plotting package has also been implemented as well as the Markov texture generation programs and an improved version of the texture analysis program.

4. Publications

Substantial progress has been achieved during this contract year and much of this progress has been described in a number of papers and invited presentations.

Papers published during the contract period include the following:

1. Image Segmentation; Dahlem Workshop on Biomedical Pattern Recognition; May 1979, Berlin, Germany; Charles A. Harlow (Invited)
2. On Radiographic Image Analysis; Proceedings Joint American College of Radiology-IEEE Conference on Computers in Radiology; June 18, 1979; Los Angeles, California; Charles A. Harlow. (Invited)
3. Image Segmentation and Texture Analysis; Charles A. Harlow; R. W. Conners; Proc. SPIE Conference; San Diego, California; August 1979. (Invited)
4. A Theoretical Comparison of Texture Algorithms; R. W. Conners; C. A. Harlow; Accepted for Publication; IEEE Transactions on Pattern Analysis and Machine Intelligence.
5. Image Analysis Techniques and Remote Sensing; Corps of Engineers Remote Sensing Symposium; October 1979; Washington, D.C.; C. A. Harlow; J. Hill; R. W. Conners; (Invited).
6. The Theoretical Development of a Texture Algorithm Based on Statistical Models of Texture; Charles A. Harlow; R. W. Conners; Workshop in Image Modeling; Chicago, Illinois; August 1979; (Invited).
7. Towards a Structural Texture Analysis Based Upon Statistical Methods; R. W. Conners; C.A. Harlow; to appear in Image Modeling, Prentice-Hall, Azriel Rosenfeld (Ed.).

5. List of Personnel

Charles A. Harlow - Professor

Richard W. Conners - Professor

Kingyao Lin - Graduate Student, Master's Degree

6. Interactions

During the first year of the project, substantial efforts have been made to interact with U.S. government laboratories interested in image processing and related research. Specific contacts are as follows:

a. RADC, Griffiss AFB
   Rome, N.Y.
   D. Bush

b. DMAAC
   St. Louis, Missouri
   Dan W. Rusco
   Jerry Becker

c. U.S. Army Corps of Engineers
   E. Link
   V. Lagarde
   Environmental Laboratory
   Vicksberg, MS

d. NORDA
   Navel Ocean Research and Development Activity
   NSTL Station, MS 39529
   R. J. Holyer

e. NASA
   National Space Technology Lab
   NSTL Station, MS 39529
   R. Estess
   R. Pearson

DAT

ILM